Design of RF Power for Couplers for Accelerator Cavities using COMSOL Multiphysics

Rajesh Kumar
IADD
BARC, Mumbai- 85
Plan of Talk

- Brief Introduction to RF Couplers
- Design of waveguide iris type couplers
- Design of Coaxial loop type couplers
- Preliminary Thermal analysis of couplers for Superconducting cavities
Typical RF system for accelerators

RF Amplifier → Circulator → DC → RF Coupler

Matched load

50 keV beam → 50 kW, 350 MHz Coupler → 400 keV beam

High vacuum Components

E field in cavity

Rajesh Kumar's presentation at COMSOL Conference, Pune, 30th Oct, 2015
Different type of coupling tuning schemes

Coupling Coefficient ($\beta$) = 1 => Critical coupling => No reflections
$\beta > 1$ => Over-coupling
$\beta < 1$ => under coupling;
$\beta = \frac{Z}{Z_0} = \frac{Q_o}{Q_{ext}}$

Coupling variation by iris rotation in the plane of incoming WG-proposed by author

Coupling variation by changing iris dimensions or tuner

Coupling variation by changing probe length

Coupling variation by iris rotation, or change of loop area

Incoming power from Coax/ WG-Coax transition
Ridge waveguide iris coupler

Design goals:

Return loss: Better than -20 dB at 352.2 MHz

Cavity frequency shift: < 0.03 %

Power level: 250 kW CW
RF design steps for Ridge waveguide coupler

- Finalize the port size on RF cavity and calculate iris dimensions to obtain desired coupling by simulations. RF cavity model is required at this stage.
- In the coupler designed for LEHIPA, Incoming waveguide WR2300 (584.2 mm by 146.05 mm) is to be reduced to 190 mm by 35 mm. The required transition is realized in ridge waveguide form and optimized to obtain required specs using EM solver.
- Maximum Electric and magnetic fields are estimated using the solver for the required power of 250 kW at 352.2 MHz.
- Parametric studies are carried out to know the sensitivity of Return loss and design frequency to the changes in dimensions.
RF Simulations for Coupling Coefficient

- Half Height WR2300 waveguide is reduced to small cross-section on the RFQ cavity
- Ridge loading is used to maintain the same cut-off and impedance match
- Cavity Frequency shift caused by the coupler is < 0.03 %

Rajesh Kumar's presentation at COMSOL Conference, Pune, 30th Oct, 2015
Straight ridge transition based coupler for 352.2 MHz

(a) Top view of the coupler       (b) cross-section view of coupler

Rajesh Kumar's presentation at COMSOL Conference, Pune, 30th Oct, 2015
COMSOL simulation model of straight ridge waveguide coupler
Optimized dimensions for straight ridge transition based coupler

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( w )</td>
<td>WR2300 width</td>
<td>584.2</td>
</tr>
<tr>
<td>( h )</td>
<td>WR2300 height</td>
<td>146.05</td>
</tr>
<tr>
<td>( wl )</td>
<td>Input Port length</td>
<td>160</td>
</tr>
<tr>
<td>( c-ow )</td>
<td>Central section- overall width</td>
<td>334</td>
</tr>
<tr>
<td>( cw )</td>
<td>Central ridge width</td>
<td>69.4</td>
</tr>
<tr>
<td>( cl )</td>
<td>Central ridge length</td>
<td>315</td>
</tr>
<tr>
<td>( cg )</td>
<td>Central ridge gap</td>
<td>11.5</td>
</tr>
<tr>
<td>( ch )</td>
<td>Central ridge height</td>
<td>64</td>
</tr>
<tr>
<td>( ew )</td>
<td>End ridge width</td>
<td>89</td>
</tr>
<tr>
<td>( e-ow )</td>
<td>End section- overall width</td>
<td>189</td>
</tr>
<tr>
<td>( eg )</td>
<td>End ridge gap</td>
<td>1.55</td>
</tr>
<tr>
<td>( eh )</td>
<td>End ridge height</td>
<td>35</td>
</tr>
<tr>
<td>( el )</td>
<td>Output Port length</td>
<td>20</td>
</tr>
</tbody>
</table>
RF Simulations for Return loss of coupler transition

Iterative simulations are performed in COMSOL to reach optimized dimensions.

BW ~ 4 MHz

Rajesh Kumar's presentation at COMSOL Conference, Pune, 30th Oct, 2015
Preliminary Coupled RF-Thermal simulations

- Electromagnetic waves-frequency domain (emw) and heat transfer in solids (ht) modules are used
- Boundary electromagnetic heat source is used for RF loss on copper surface
- Convective heat transfer coefficient = 1000 W/M2k, Ambient temp. = 293 K
- $P_{in}$ at Port 1 is taken as 250 kW at 352.2 MHz

Max. surface temp. should be < 50 deg. C to avoid thermo-structural effects on performance

Rajesh Kumar's presentation at COMSOL Conference, Pune, 30th Oct, 2015
Coupled RF-Thermal simulations contd.

freq(13)=3.52e8  Surface: Temperature (K)
Design of Coaxial Couplers

- Electromagnetic waves-frequency domain (emw) module is used.
- 6 1/8" rigid coaxial line made up of Copper is tapered to 1 5/8" using a 160 mm long tapered transition.
- Capacitive discontinuity of alumina discs is cancelled by quarter wave shorted stub.
- Shorted stub is used to circulate cooling water to inner conductor.
- Return loss is optimized for 350 MHz.
Return loss optimization of Coaxial Couplers
Preliminary Thermal analysis of coaxial couplers for superconducting cavities

- Heat transfer in solids (ht) module is used in these simulations
- Outer conductor of coupler with 72.2 mm inner diameter and 220 mm length is simulated for different thicknesses
- Thermal strap at 10K is used to optimize static thermal load on to 2 K helium cryogenic system
### Static heat load optimization

<table>
<thead>
<tr>
<th>ID (mm)</th>
<th>OD (mm)</th>
<th>Thickness (mm)</th>
<th>Heat load to 2 K system</th>
<th>Total heat load (W)</th>
<th>d (Thermal strap position in mm)</th>
<th>Length (mm)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>72.2</td>
<td>73.5</td>
<td>0.65</td>
<td>0.31</td>
<td>4.9</td>
<td>50</td>
<td>220</td>
<td>SS- (COMSOL material library SS-ASI4340)</td>
</tr>
<tr>
<td>72.2</td>
<td>73.8</td>
<td>0.80</td>
<td>0.38</td>
<td>6.03</td>
<td>50</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>72.2</td>
<td>74.1</td>
<td>0.95</td>
<td>0.46</td>
<td>7.17</td>
<td>50</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>72.2</td>
<td>74.4</td>
<td>1.10</td>
<td>0.53</td>
<td>8.32</td>
<td>50</td>
<td>220</td>
<td></td>
</tr>
<tr>
<td>72.2</td>
<td>74.7</td>
<td>1.25</td>
<td>0.60</td>
<td>9.47</td>
<td>50</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>72.2</td>
<td>75.0</td>
<td>1.40</td>
<td>0.67</td>
<td>10.62</td>
<td>50</td>
<td>220</td>
<td></td>
</tr>
</tbody>
</table>

*Thickness of outer conductor, thermal strap position is optimized to have min. heat load onto 2K cryogenic system*
Typical RF couplers designed and developed

50 kW, 350 MHz peak peak power Coaxial loop coupler of 40 mm dia. and 150 mm length

50 kW CW, 350 MHz Coaxial loop coupler of 155 mm dia. and 400 mm length

250 kW, 352.2 MHz Waveguide coupler of width 584.2 mm, height 146.05 mm and length of 600 mm
High power ridge waveguide coupler with tuners (250 kW, 352.2 MHz) for LEHIPA

The coupler is being used on RFQ cavities of LEHIPA and have been conditioned up to 280 kW, 2.5 ms, 1Hz

Fabricated ridge waveguide Coupler and tuners. The coupler has been successfully tuned to the RFQ cavity for -27 dB Return loss
Conclusions

- COMSOL Multiphysics is used to design waveguide iris couplers using RF module. Preliminary RF-thermal analysis is carried out.

- RF design of coaxial couplers is carried out.

- Preliminary studies for static heat load optimization on to 2 K cryogenic system is done for Coaxial RF coupler’s outer conductor.

- Coupled RF-Thermal-structural simulations will be carried out to design RF couplers for superconducting cavities.
Thanks a lot.